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13. ABSTRACT ***(Maximum 200 Words)***
CS 1082 was a FY98 New Start. Our broad objective is to transition information about effects of DoD sound types on marine mammal auditory anatomy and acoustic ecology to predictive models and mitigation tools. Currently, the DoDlacks scientifically defensible information concerning the safe operation of many of their training and testing systems in the presence of marine mammals. There is only very little direct information about what sound frequency-intensity combinations may damage the hearing of marine mammals. This effort responds directly to the DoD capability to comply with the National Environmental Policy Act requirements and will contribute directly to answering the National Research Council's Research Needs related to the effect of low-frequency sound on marine mammals (1994).

This project consists of three inter-related tasks. Task 1 consists of otopatholocigal analyses of maringe mammal ears. Task 2 consists of otopathological analyses of baleen whatle ears, the results of which will motivate development of a biomimetic model of baleen whate hearing and responsiveness to DoD sound types. Task 3 utilizes predictions about sensitivity generated in Task 2, plus statistical sampling models and acoustical classification algorithms, to develop a capability to automate the use of the US Navy's Integrated Undersea Surveillance System (IUSS) for mapping the distribution of whales.

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SERDP FY98 ANNUAL TECHNICAL REPORT

PROJECT CS-1082

Information and Technology Tools for Assessment and Prediction of the Potential Effects of Military Noise on Marine Mammals.

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Background:

CS1082 was a FY98 New Start. Our broad objective is to transition information about effects of DoD sound types on marine mammal auditory anatomy and acoustic ecology to predictive models and mitigation tools. Currently, the DoD lacks scientifically defensible information concerning the safe operation of many of their training and testing systems (e.g., Low Frequency Active sonar (LFA) and Shipshock) in the presence of marine mammals. There is only very little direct information about what sound frequency-intensity combinations may damage the hearing of marine mammals. This effort responds directly to the DoD capability to comply with the National Environmental Policy Act requirements and will contribute directly to answering the National Research Council's Research Needs related to the effect of low-frequency sound on marine mammals (1994).

This project consists of three inter-related tasks. Task 1 consists of otopathological analyses of marine mammal ears. Task 2 consists of otopathological analyses of baleen whale ears, the results of which will motivate development of a biomimetic model of baleen whale hearing and responsiveness to DoD sound types. Task 3 utilizes predictions about sensitivity generated in Task 2, plus statistical sampling models and acoustical classification algorithms, to develop a capability to automate the use of the US Navy's Integrated Undersea Surveillance System (IUSS) for mapping the distribution of whales.

Task 1.

Objective.

Task 1 is a study comparing the evidence for normal versus pathological changes of marine mammal ear anatomy. Our objective is to provide evidence of the relative occurrence of presbycusis (age-related hearing loss), sociocusis (sociogender-related hearing loss), and pathology (e.g., disease-related hearing loss). Although there is increasing concern over the effects on marine mammals of man made sound in the oceans, we have little direct information about what sound frequency-intensity combinations damage marine mammal ears. This task provides first-ever effort directed at understanding whether marine mammals, like humans and other land mammals, have progressive, age-related hearing changes or disease that can potentially skew our understanding of noise effects on these animals. However, before we can understand how human activity may impact hearing of any marine species, it is important to know 1) the status of hearing in wild populations; 2) what natural hearing changes with age can be expected in any given marine mammal, and 3) what hearing pathologies commonly affect these animals.

Approach.

To date, there has been no systematic study of longitudinal changes in hearing in marine mammals. Biomedical imaging (CT/MRI) and light microscope analyses of these ears are used to create three-dimensional models of the ear from which species-specific basilar membrane-frequency ranges and distributions can be estimated. Data and techniques developed in the study of normal marine mammal ears are combined with knowledge derived from human otopathologic studies to provide a base for otopathologic analysis of marine mammal ears. Ears from captive odontocetes and pinnipeds with known audiograms are examined with CT, MRI, and light microscopy.

Three-dimensional reconstructions are used for morphometric analyses of the nature and extent of inner ear pathologies in all ears from older animals with documented hearing losses. Locations of significant pathologies are mapped onto the basilar membrane frequency distribution graphs generated for that species from the previous research to determine whether predicted hearing losses coincide with the audiometric data for the animal. Multiple animal comparisons show what are the significant pathologies and how each pathology progresses with time. Specimens from younger animals will be analyzed to determine normal frequency dependent distributions of ganglion cells, morphometric variations in ganglion cell types, and cochlear duct specializations.

Accomplishments.

Task 1 is ahead of schedule on CT scans of ear tissues, and on schedule with histological analyses. At this time, the work on Task 1 is in the essential preliminary phase of preparing all specimens required for pathologic and model data collection. The preparatory work consists of physically processing and sectioning the ear tissues through controlled chemical demineralizations followed by cutting and staining up to 1500 sections of each ear. Histological preparation occurs in serial order, starting with decalcification, followed by embedding, staining of tissue, and slide mounting for microscopic analyses. When completed, the histological preparations are ready for counting of transduction structures and morphologic measurement. Fundamental morphologic data have been collected on all projected specimens from CT and MRI scans, but the histologies will be crucial for definitive conclusions about the disease states in particular of damaged ears.

Task 1. Specimen pool and analysis status as of 01 December 1998.

Subject	A-gram	Ears	Histology		CT		MR	
			Prep	Done	Schedule	Done	Schedule	Done
Tg419M	Y	2	2 DESM	2	2	2	2	2
Tt728M	?	2	2 D	.	.	.	.	.
Tt768M	?	2	2 D	.	.	.	.	.
Tt001F	Y	2	1 DESM		2	2	.	.
Tt780F	Y	1	1 DE	.	1	1	.	.
Tt000M	Y	2	1 DE	.	2	2	.	.
Tt675F	Y	2	2 DESM	2	2	2	2	2
Tt580F	?	1	1 DE	.	1	1	.	.
Tx580c	--	2	2 DE	.	2	2	.	.

Imaging studies were completed on nearly double the number of specimens originally projected in the first year (current total 12 scan sets). Histologic data were collected on four ears from two animals and all others are well into the processing. Progress is summarized in Table 1. The data from these four ears, coupled with Ultra-High Resolution CT data from all the remaining specimens, show that male odontocetes are clearly subject to substantial high frequency loss. Moreover, they also suggest that females may be more resistant to such losses, perhaps because of an underlying biochemical process for resisting fatigue of auditory elements.

Task 2.

Objective.

We investigate the potential effects of man-made low-frequency sound on the hearing of baleen whales through construction of a biomimetic computer model of baleen whale hearing. Man-made low-frequency sound (less than 1000 Hz) has been identified as potentially harmful to marine mammals (NRC, 1994; Richardson et al., 1995). For example, baleen whales communicate using very low-frequency sounds (e.g., Helweg et al., 1992) and thus are at great risk of hearing damage and masking of communication calls caused by low-frequency sounds generated by DoD activity. Therefore, the ability to predict potential effects of military sound sources on marine mammals is crucial to formulating proper assessments, monitoring, and mitigation regimes for any DoD activity that may impact on marine mammals (NRC, 1994; Richardson et al., 1995).

Task 2 utilizes state-of-the-art knowledge about baleen whale ears to motivate a computational model of baleen whale hearing ability. This task is linked closely with anatomical analyses produced by Task 1, because development of the model will depend on the state of our knowledge about marine mammal ear anatomy. The biomimetic computer model is based upon cetacean sensory processes, performance, and mysticete (baleen whale) auditory morphology. In FY98, the model was used to simulate a baleen whale audiogram.

Approach.

The completed model allows the user to simulate the effects of man-made sounds on the hearing sensitivity of large baleen whales such as the humpback whale. The models are created using anatomically-derived hearing sensitivity models for baleen whales, along with data on cetacean auditory processes (e.g., Ketten, 1994; Moore et al., 1995). These data are used to retro-fit an existing biomimetic model of cetacean VIIIth nerve auditory processes (Moore et al., 1991; Roitblat et al., 1993), and to explore the possible utility of extant cochlear simulators. The model is dovetailed with Ketten's mapping of auditory anatomy onto equations for auditory sensitivity (see TASK 1), which provides one core function necessary to predict whale hearing responses.

Accomplishments.

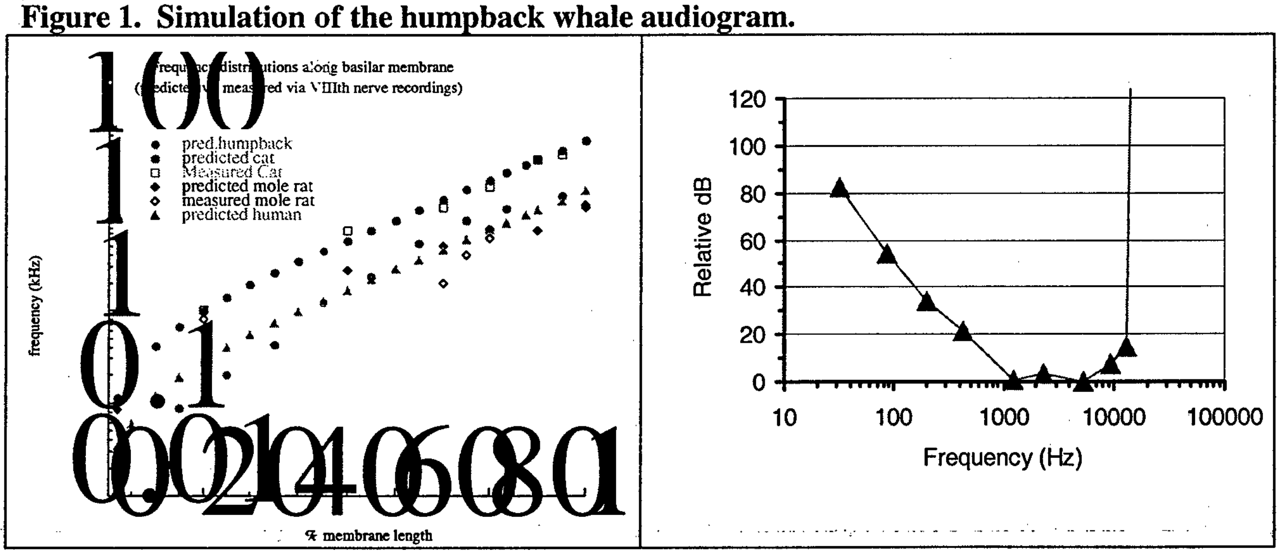
Task 2 is ahead of schedule on CT scans and histological analyses, and on-schedule with compuational ear modeling. At this time, the anatomical work on Task 2 is in the essential preliminary phase of preparing all specimens required for model data collection. The preparatory work consists of physically processing and sectioning material the tissues through controlled chemical demineralizations followed by cutting and staining up to 1500 sections of each ear. For a baleen whale ear, this process can take up to 18 months.

Imaging studies were completed on nearly double the number of specimens originally projected in the first year (current totals 15 scan sets). A preliminary frequency curve for humpback whale frequency range has been completed. Because of the crucial need for baleen whale hearing data, an accelerated processing method was attempted on one test humpback whale ear. The outcome was successful. Based on measurements of the inner ear membranes from histologies of this specimen, a preliminary humpback frequency distribution curve was generated. These data are presented in the left panel of Figure 1. Note that all curves are actual; they have not been derived from functions. The humpback data (blue) display the distribution of frequencies typical of auditory generalists, such as humans (red) and cats (gray). Bottlenose dolphins also have generalist ears. This means that they have sensitivity that varies monotonically over a broad range of frequencies, as compared to ears of auditory specialists such as harbor porpoises, which have nonlinear frequency enhanced regions along their basilar membranes.

Although projections of specific impacts to each target species must wait for additional analyses, the CT and preliminary humpback data clearly demonstrate that we were able to obtain adequate numbers and types of ear specimens to accomplish the range of species required for the projected tasks. The resulting audiogram is presented in the right panel of Figure 1. This is a first-ever prediction of the frequency range and relative sensitivity of a baleen whale species. Most important, we have in place a proto-model of hearing for one baleen species.

The 10-point humpback whale inner ear membrane frequency mapping function was used to adapt the filter-bank model of bottlenose dolphin hearing. Audiometric neural tuning curve design is being benchmarked against generalist audiogram functions using Evolutionary Computation techniques. Early results are being generated using the number of filters, center frequency, fractional bandwidth, and relative amplitude as free parameters in the computation space.

Figure 1. Simulation of the humpback whale audiogram.



Task 3.

Objective.

One of the worst surprises that could co-occur with a DoD Operation is unpredicted mortality due to lack of knowledge on the whereabouts of Threatened or Endangered marine mammals species. The capability to formulate strong Environmental Risk Assessments for DoD activities includes consideration of alternative OPs sites. This highlights the critical need for information about the distribution of Threatened & Endangered baleen whale species in the toolkit of DoD environmental program managers. The almost total lack of information about the distribution of these whales lies in stark contrast to the need for compliance with NEPA requirements.

Task 3 utilizes Navy SOund SUrveillance System assets (SOSUS) to study the movement patterns of large whales in the wild. The objective is to automate the use of the US Navy's Integrated Undersea Surveillance System (IUSS) for identifying "hotspots" (seasonal and/or geographic peaks) in the abundance of whales in Southern California waters. Automated capability is developed by integrating predictions about auditory sensitivity generated in Task 2 with development of statistical sampling techniques and acoustical classification algorithms.

Approach.

The monumental volumes of acoustical data that stream in to each SOSUS facility have proven an obstacle to traditional analytic techniques, which has hampered delivery of finished analyses to DOD Environmental Managers. To deliver the needed analyses in a timely fashion, it is imperative that data available through Dual Uses be subjected to data sampling, selection and reduction schemes. To this end, we are developing (a) the capability to automate the detection and classification of selected whale vocalizations, (b) to statistically sample regions of ocean using IUSS Imaging assets, and (c) to integrate classifier algorithms and sampling schemes. In FY98, automated classification was systematically explored using a complement of nonlinear dynamic classifier algorithms and philosophies (such as Adaptive Resonance Theory networks, dynamic time warping, Cepstral Cross-Correlation, matched, and replicate filters). The comparative utility of each classification algorithm was benchmarked using a standardized database of whale vocalizations in SOSUS format.

Accomplishments.

Task 3 is on-schedule in all phases of the research plan. The decommissioned SOSUS assets at San Nicholas Island (SNI) were reactivated and evaluated. The T1 encrypted communications link between SNI and the SPAWAR Surveillance Test & Integration Center (STIC) was activated and verified. We have demonstrated full capability for data acquisition, signal processing, and storage of SNI data using STIC network systems at the SPAWAR STIC. An inexpensive COTS hardware/software system for statistical sampling of Southern California blue and fin whale abundance and distribution was developed and installed at SNI. Data have been collected on a statistical sampling scheme from 01 April – 30 September 1998, providing over 1080 hours of raw ocean acoustic data for analysis. The utility of using a decommissioned site, plus IUSS signal processing assets, is being assessed. The costs and benefits of using the extant IUSS assets are compared against the use of custom contemporary technology.

Blue and fin whale calls are very stereotypical. Blue whale “A” and “B” calls have fundamental frequencies of approximately 17 Hz, narrow bandwidth and well-defined harmonic structure, and typical duration of 15-25 sec. Fin whale “pulses” have fundamental frequencies of

approximately 17 Hz, but are broadband in nature and short (~ 1 sec) duration. The homogeneous call structure lends itself to automated detection. Stable acoustical differences in call structure lend themselves to automated species identification. In FY98, we have benchmarked a series of bioacoustical call identification algorithms against a set of blue and fin whale calls while systematically manipulating the signal to noise ratio. The results demonstrated a typical tradeoff of speed versus accuracy. We cannot present the results because they are in review for sanitization prior to release.

Appendix 1. Products.

We anticipate publication of at least two reports in FY99, and will present our FY98 results at the International Bio-Acoustical Conference in April 1999. The results are in strong demand. We have provided Task 2 results to PMS-400DE, who ard providing funding for one aspect of the modeling effort (Evolutionary Computation of Filter Design). We have shared Task 3 results with the SSC-SD Code D711 Living Marine Resource Risk Assessment effort, the Pt. Mugu Naval Air Weapons Station Test Range Environmental Impact Statement effort, and SCRIPPS Marine Physics Laboratory efforts. We also have been approached to provide data to future shock trial Environmental Impact Statement efforts. Currently we are in discussion with Pt. Mugu and Pawtuxet facilities, each of which has expressed interest in purchasing a Task 3 hardware/software suite when the effort has matured.

Peer Reviewed Papers:

Brill, R.L., P.W.B. Moore, L.A. Dankiewicz, and D.R. Ketten (1998) Pan bone thresholds and evidence of hearing loss in an Atlantic bottlenose dolphin (*Tursiops truncatus*) (submitted, JASA).

Helweg, D.A., Cato, D.H., Jenkins, P.F., Garrigue, C. & McCauley, R.D. (1998). Geographic variation in South Pacific humpback whale songs. *Behaviour*, **135**, 1-27.

Ketten, D.R. (1997) Structure and Function in Whale Ears. *Bioacoustics*, **8**(1), 103-136.

Ketten, D.R. (1998) Marine mammal ears: An Anatomical perspective on underwater hearing. Proc. Int. Cong. on Acoust., vol. 3, pp.1657-1660.

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Altes, R.A., Moore, P.W. & Helweg, D.A. (1998). Tomographic image reconstruction of MCM targets using synthetic dolphin signals. *SSC-SD Technical Document 2993.*

Helweg, D.A. (1998). Automating the acoustic monitoring of New Zealand waters for migrating humpback whales (*Megaptera novaeangliae*). *SSC-SD Technical Report 1765.*

Ketten, D.R. (1998) Marine mammal Hearing and Acoustic Trauma: Basic Mechanisms, Marine Adaptations, and Beaked Whale Anomalies. in: Report of the Bioacoustics Panel, NATO/SACLANT, A. D'Amico and W. Verboom (eds.), pp. 2-21, 2-63-78.

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Brill, R.L., P. W. B. Moore, L. A. Dankiewicz, and D.R. Ketten (Dec., 1997) Evidence of hearing loss in an Atlantic bottlenose dolphin (Tursiops truncatus). Invited paper, 134th Meeting, Acoustical Society of America.

Brill, R.L., P. W. B. Moore, L. A. Dankiewicz, and D.R. Ketten (May, 1998) Specialized sound sites in the dolphin's peripheral hearing system. Fourth International Biosonar Conference, Algarve, Portugal.

Helweg, D.A. & Moore, P.W.B. (1997). Aspect-independent classification of "dolphin"-ensonified mines using Choi-Williams representations. Invited paper, 134th Meeting, Acoustical Society of America.

Helweg, D.A. & Moore, P.W.B. (1998). Adaptive classification of ensonified underwater targets. Invited paper, Fourth International Biosonar Conference, Algarve, Portugal.

Helweg, D.A. (April 1999). A computational model of humpback whale hearing. International Bio-Acoustical Council, Chartres, France.

Helweg, D.A. (April 1999). Automatic detection and species identification of blue and fin whales. International Bio-Acoustical Council, Chartres, France.

Helweg, D.A., Carder, D.A. & Ridgway, S.H. (1997). A portable virtual instrument for collection of cetacean auditory evoked potentials. Invited paper, 134th Meeting, Acoustical Society of America.

Houser, D.S., Helweg, D.A. & Moore, P.W.B. (1997). Classification of dolphin echolocation clicks by means of energy and frequency distributions. Invited paper, 134th Meeting, Acoustical Society of America.

Ketten, D.R. (1998) Marine mammal ears: An Anatomical perspective on underwater hearing. Plenary Lecture, joint meeting, International Congress on Acoustics/Acoustical Society of America.

Ketten, D.R. (1998) In Vivo Analyses of Insertion Trauma, Invited lecutre, Surgeon's Workshop on Cochlear Implantattion, Amer. Academy. of Otolaryngology-Head and Neck Surgery

Ketten, D.R. (1998) In Vivo Imaging of Intracochlear Electrode Positions, Invited lecture, Cochlear Implant Workshop, Amer. Academy. of Otolaryngology-Head and Neck Surgery

Ketten, D.R. (April, 1998) Marine mammal Hearing and Acoustic Trauma: Basic Mechanisms, Marine Adaptations, and Beaked Whale Anomalies. Invited lecture, Bioacoustics Session. NATO/SACLANT Mtg. on LFS Effects, La Spezia, Italy.

Ketten, D.R. (Jan. 1998) Man-made noise in the oceans: Irrelevant or irreparable? Plenary lecture, World Marine Mammal Conference; joint meeting., European Cetacean Society and the Society for Marine Mammalogy, Monaco.

Ketten, D.R. (May, 1998) Dolphin and Bat Sonar: Convergence, Divergence, or Parallelism. Fourth International Biosonar Conference, Algarve, Portugal.

Ketten, D.R., Dolphin, W.F., Chittick, E.J., Krum, H.N., and Merigo, C. (Jan., 1998) In vivo imaging correlated with otoacoustic emissions as a metric for ear disease in seals, World Marine Mammal Conference; joint meeting., European Cetacean Society and the Society for Marine Mammalogy, Monaco.

Ketten, D.R., P. W. B. Moore, L. A. Dankiewicz, and W. Van Bonn (Dec., 1997) The slippery slope of a Johnsonian ear: Natural variability versus natural loss. Invited paper, 134th Meeting, Acoustical Society of America.

Ketten. D.R (Jan, 1998) Imaging the Auditory System from Stem to Stern: Inner ear disease and cochlear implantation, Invited Lecture, Special Session on Imaging, American Academy of Audiology.

Meng, J., J. Shoshani, and D. Ketten (Oct., 1997) Evolutionary Evidence for Infrasonic Sound and Hearing in Elephants, Society for Vertebrate Paleontology.

Miller, L.A. & Helweg, D.A. (April, 1997). Bats, humans and neural networks discriminate amplitude-modulated FM echoes. International Bio-Acoustical Council, Chartres, France.